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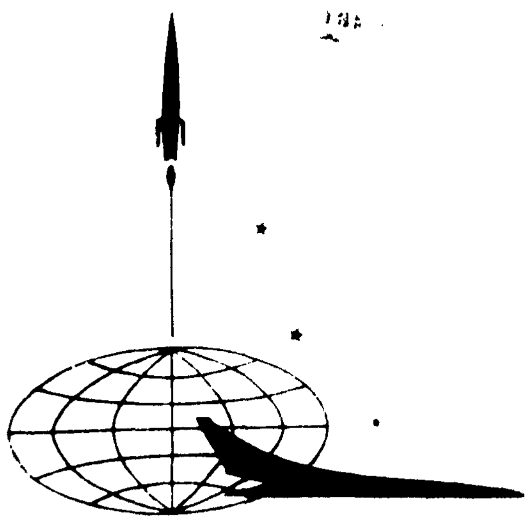
Surveys of Soviet-Bloc Scientific and Technical Literature

METEOR PHYSICS AND EXTRATERRESTRIAL MATTER

Comprehensive Report



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FOREWORD

This comprehensive report has been prepared in response to ATD Work Assignment No. 79, Task 44. It deals with the physical phenomena associated with the flight of meteors in terrestrial atmosphere and their origin in interstellar space. The report is based on Soviet literature published since 1957 which is available at the Library of Congress. The introduction lists the Soviet observation points where meteor investigations are carried out and describes the methods used in these investigations and various concepts of the nature of meteors. An attempt was made to compare Soviet achievements with similar Western works and to estimate the state of investigations in the USSR and in the West. Chapter I deals with meteoric matter in interplanetary space as it is reported in Soviet publications. Chapter II contains abstracts from Soviet publications concerned with the ionization processes of meteor trails, which are important in upper-atomosphere studies. Chapter III deals with the physical properties of moving meteors. Chapter IV contains a review of Soviet articles dealing with the Tunguska meteorite of 1908. Chapter V contains a review of a book concerned with meteors, published in the Soviet Union. The writer's conclusions contain comments on the general approach to the problem as well as on individual works.

TRANSLATIONS: Literature sources indicated in the bibliography have been translated into English with the exception of *Meteoritical* and the Transactions of the Physical and Technical Institute of the Turkmen Academy of Sciences, but not all of these translations are available in the Library of Congress. *Astronomicheskiy zhurnal* is translated from v. 34, 1957, to 1963 by the American Institute of Physics, 335 East 45th Street, New York 17, N. Y. Volumes 1 through 3 of *Geomagnetizm i astronomiya* have been translated by the American Geophysical Union, 1515 Massachusetts Avenue, N.W., Washington 5, D. C. *Uspekhi fizicheskikh nauk* is translated by three agencies: 1) Israel Program for Scientific Translations, Jerusalem (sponsored by the U. S. Atomic Energy Commission); 2) International Physical Index, 1909 Park Avenue, New York 35, N. Y.; and 3) American Institute of Physics. Those translations of articles which are available in the Library of Congress are noted at the end of the abstract.

Full translations of some of the source materials used in this report may be available from other agencies or commercially. Interested readers may obtain translation data for individual sources by indicating source numbers from the bibliography list on the form attached at the end of this report and returning it to the Aerospace Technology Division.

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METEOR PHYSICS AND EXTRATERRESTRIAL MATTER

INTRODUCTION

Soviet scientists have paid considerable attention to meteoric phenomena in the terrestrial atmosphere. Investigations have been carried out from both theoretical and experimental points of view. The theoretical studies are concentrated mostly in the Institute of Physics of the Earth.

Special stations for meteor observations are established in Dushanbe, Ashkhabad, Simforopol', and Odessa. Meteor observations are also performed at the main astronomical observatories of the Soviet Union. The Dushanbe Station (formerly Stalinabad), located at the Tadzhik Astronomical Observatory of the State Academy of sciences at Dushanbe, is equipped with special instruments for photographing meteors. Fundamental observational investigations of meteors are carried out at the Astrophyscial Laboratory of the Turkmen Academy of Sciences.

Among the Soviet scientists who have devoted special attention to theoretical meteor investigations are Levin, Fesenkov, Bronshten, Stanyukovich, and Al'pert. Experimental skill has been shown by Astapovich, Katasev, Fedynskiy, Fialko, Lysenko, Nazarova, Nemirova, et al. Russian scientists have paid special attention to studying the heights above the earth's surface at which the meteors burn up and the distribution of ionized gas around the meteor. Models of the shape of ionized-gas distribution in front and behind meteors have been constructed.

In 1908 a powerful meteorite struck the earth's surface in Middle Siberia near the Podkamennaya Tunguska River, a tributary of the Yenisey. However, the place of impact was not investigated until recently. Data obtained by several recent expeditions has provided material for numerous articles examining the nature of the Tunguska meteorite. One group of scientists believed that the earth was struck by a large meteor, which, before reaching the earth's surface, had been fragmentized at a very high temperature. The majority of investigators, however, assumed that the incident represented the collision of a comet with the earth because of the absence of meteoric fragments at the place of impact. Combining their own investigations with Western literature sources led to the compilation of a series of books on meteoric phenomena.

CHAPTER I. METEORIC MATTER IN INTERPLANETARY SPACE

1. Ye. I. Fialko studied the mean number of meteors with a restricted mass which could be recorded by radar per unit area per unit time. The number of meteors with masses from m to m + Δm which pass through a square area unit during a given time unit is determined by the formula $\Delta N = f(m)\Delta m$. The number of meteors of a shower which are recorded in the time interval from t_1 to t_2 at heights from h_1 to h_2 within a sector of the echo plane from θ_1 to θ_2 degrees is given by the following formula for normal reflection of radio waves:

$$N = \int_{t_1}^{t_2} \frac{dt}{\sin^2\chi} \int_{\theta_1}^{\theta_2} \frac{d\theta}{\cos^2\theta} \int_{h_1}^{h_2} h\,dh \int_{m_{min}}^{\infty} f(m)\,dm,$$

where χ is the zenithal distance of the shower radiant, θ is an angle in the echo plane, min is a minimum index of the meteor body which is able to create an ionized trail. According to Kaiser's formula,

$$m_{min} = \left(\alpha_{min}^{1/2} \sqrt{\frac{Q\mu H}{\beta p}} + \frac{pv^2}{3Q\cos\chi}\right)^3,$$

where H is the height of a homogeneous atmosphere, p is its pressure in a column of normal reflection, v is the meteor velocity, β is the probability of ionization, μ is the atomic mass of the meteor matter, Q is a coefficient characterizing the physical and geometrical properties of meteors, α_{min} is the minimum electron density that can be recorded. In the function of f(m) = b/ms, C and S are constants. The minimum electron density is determined by the formula:

$$\alpha_{min} = B \sqrt{\frac{\varepsilon_{tr} R^3}{P_r \lambda^3}} \frac{1}{G} \frac{\Delta^{0.5}}{1 - e^{-1.5\Delta^{0.5}}} e^{(2\pi/\lambda)^2 (a^2 + 4DT_{min})},$$

where ε_{tr} is the power of the threshold signal of the receiver, R is the slope distance from the radar to the meteor trajectory, P_r is the radiation power of the impulse, λ is the wavelength, G the coefficient of the antenna directivity, B = 8 x 10^{13} , a is the initial radius of the meteoric trail, D is the diffusion coefficient, T_m is the minimum of time necessary for recording, and

$$\Delta = \frac{16\pi^2 D R^{1/2}}{v\lambda^{3/2}}.$$

[Translation is available at the Library of Congress]

2. From April 1960 to March 1961, regular monthly investigations of wind velocities in the meteor zone were carried out by I. A. Lysenko, using radar measurements. Measurements were performed on a frequency of 36.9 Mc with a transmitter power of 75 kw over a period of 5—7 days for the purpose of detecting winds in the EW and NS directions. The height of winds was determined with an accuracy of $\pm$ 4 km; wind velocity, with an accuracy of $\pm$30%. The results of velocity changes which were obtained by harmonic analysis are represented graphically. A good agreement between the theoretical curves and the experimental data proved that terms higher than those of the third power may be omitted. The 24-hr changes did not show a regular rate, but the 12-hr changes exhibited a seasonal character with larger amplitudes in winter and smaller amplitudes in summer. The NS component, which rotates, may be represented as a clockwise-rotating vector. The EW component shows winds with a predominantly easterly direction and with a velocity of 30—35 msec^{-1} in June and January. The dependence of the wind velocity on height is represented graphically, showing an increase of velocity with an increase in height. These graphs represent the 12-hr component at night. The positive gradient is equal to 1—1.5 msec^{-1}/km^{-1}. Gradients obtained are in good agreement with the tidal resonance theory; the rotation of the velocity vectors also occurs according to the tidal resonance theory. Changes of meteor paths have also been observed by other investigators, who found the same variations of the 12-hr component. Only one condition of the tidal resonance theory has not been proved by experimental data, i.e., the axes of ellipses formed by rotating vectors do not coincide with the NS and EW directions. Temperature change with changes in height at 80 to 100 km shows a lower temperature in summer than in winter in the Northern Hemisphere. This phenomenon is attributed by Lysenko to the action of water vapor at those heights in summer. The rotational movement of wind vectors from north to east and from south to west is caused by the Coriolis force.

3. L. A. Katasev discusses earlier works on the formation of a dust atmosphere around the earth through the capture of meteoric particles. V. G. Fesenkov assumed that meteoric particles captured by the earth form a layer at heights of 100—103 km, the particles of which can fall on to the earth after several revolutions along their orbits. Some meteoric particles which are not captured by the earth pass through the atmosphere where resistance deforms the shape of their orbits. Katasev studied the change of an

orbit within the resistant atmosphere. The formula

$$v_h^2 = K^2\left(\frac{2}{R} - \frac{1}{a}\right),$$

where R is the radius vector of the particle and K is the Gauss constant, expresses the heliocentric velocity of the particle. The heliocentric velocity v_h consists of two parts: the geocentric velocity v within the atmosphere and the orbital velocity of the earth v_t:

$$v_h^2 = v^2 + v_t^2 - 2vv_t \cos n.$$

The change of the major semiaxis of the particle orbit is given by the formula

$$\frac{da}{dt} = 2L^2K^2 \frac{v - v_t \cos n}{(Lv^2 + Mv + N)^2} \frac{dv}{dt} \cdot$$

The motion of a spherical particle in the atmosphere is given by the formula

$$\frac{dv}{dt} = -AG\, m^{-1/3} \rho v^2,$$

where G is the coefficient of frontal resistance, ρ is the atmospheric density, and $A = 1.21\,\delta^{-2/3}$, and δ is the density of meteoric matter. Transforming the last two formulas and taking approximate values, the final formulas for the change of the major semiaxis and the eccentricity are:

$$\Delta a_i \approx -2L^2K^2 \frac{v_0^2 (2\sigma_i - 1) - v_t \cos n\, \sigma_i v_0}{[Lv_0 (2\sigma_i - 1) + Mv_0\sigma_i + N]^2} \frac{1 - \sigma_i}{\rho_i},$$

where $\sigma_i = 1 - AG_m^{-1/3} \rho_i \Delta l_i$, Δl is the path passed in the atmosphere,

$$\Delta e = \frac{1 - e^2}{2ae - R\cos\varphi} \Delta a_i,$$

where φ is the true anomaly. The main factors for orbital transformation are the meteoric velocity and the atmospheric density. The earth's attraction weakens the atmospheric resistance before the perihelion passage. After the passage the attraction slows down the velocity, and its action is added to the resistance. The particle path is given by the formula

$$\Delta l = \frac{v \sqrt{p}}{KE \sin \psi} \Delta r,$$

where Δr is the thickness of the homogeneous atmospheric layer, E is the eccentricity, and Ψ is the true anomaly. The change of the orbital elements of a particle can be determined using the given formulas. A table contains the numerical values of the orbital element changes for three particles of different masses computed for the initial velocities 15.25 km·sec^{-1} and 60.95 km·sec^{-1}. The numerical values show that very small particles of 10^{-9}g with small velocity undergo a braking effect at a height of 200 km. The velocity of such particles becomes less than the parabolic velocity at a height of 113 km, and they can be captured by the earth. Particles with larger masses can be captured in the lower atmospheric layers.

The author concludes that the earth is included within a dust atmosphere the upper limit of which is unknown, but may be not less than several thousand km. The nearer the meteoric cloud is to the earth's surface, the denser it becomes. Such meteoric clouds are assumed to exist around other planets. The orbits of particles which are not captured by the earth are transformed from long to short periodic bodies by shortening the major semiaxis.

4. T. N. Nazarova, A. K. Bektabegov, and O. D. Kamissarov described the recording of meteoric particles by the Mars-1 Interplanetary Station. The impact number of meteoric particles on a piezoelectric transmitter fastened to the side opposite the solar batteries was recorded. The sensitive surface was 1.5 m^2. The maximum of sensitivity was above the transmitter on a restricted area. On 1 November 1962 the Mars-1 station crossed the Taurides shower at 6600—42,000 km from the earth. During 100 mi., 60 impacts were recorded with particle mass of 10^7g and more. The mean impact frequency was 7×10^8 m^2 sec^1. The shower consisted of individual particle accumulations recorded at distances from 4000 to 45,000 km from each other. No impact was recorded from the middle of November through December.

From 31 December 1962 to 30 January 1963, Mars-1 encountered another shower at distances from 23 to 45 million km from the earth. In 4 hr, 13 min, and 30 sec, 104 impacts were recorded. This shower could not be identified with any of the known showers. It contained particle accumulations, with distances of 8000—190,000 km between the accumulations. On 30 January 1963 the recording device for meteoric particles ceased operating. Investigations of meteoric showers in interplanetary space outside the earth's orbit are very important to astronautics, because of the occurrence in interplanetary space of many meteoric showers which are unknown from observations on the earth's surface and which constitute a danger to cosmic probes.

5. Ye. I. Fialko studied the probability of meteoric ionization. This ionization is considered to be a result of atomic collisions of evaporated meteoric particles with atmospheric particles. The evaporation of meteoric matter and the ion collisions determine the quantity of electrons in the meteoric trail. The linear electron density, which characterizes the evaporation speed, depends upon the rate of matter evaporation and the velocity of the meteor

$$\alpha = \beta \frac{N}{v},$$

where β is the probability of ionization, v is the velocity of the meteor, and N is the number of atoms separated in evaporation process. The probability coefficient β, which depends upon the meteoric velocity, is represented by the formula

$$\beta = av^n,$$

where a and n are constants which must be determined experimentally and theoretically.

The signal power, which is normally reflected from the trail, is determined by the formula

$$\varepsilon(t) = \frac{0.7}{16\pi^2}\left(\frac{e^2}{m_e c^2}\right)^2 \frac{P_u G \lambda^3}{R^3}\left(\frac{\beta m \cos\chi}{\mu H}\right)^2 \left(\frac{p}{p_m}\right)^2 \times$$
$$\times \left(1 - \frac{1}{3}\frac{p}{p_m}\right)^4 \left(\frac{1 - e^{-1.5\Delta^{0.5}}}{1.5\Delta^{0.5}}\right)^2 e^{-2(kr_0)^2} e^{-32\pi^2 Dt/\lambda^2 \gamma_t^2},$$

where e and m_e are the charge and mass of an electron; c is the light velocity; P_u, the power of the radiating impulse; G, the coefficient of the antenna directivity; λ, the wavelength; R, the slope distance from the radar to the trail; β, the ionization probability; m, the mass of the meteoric body; χ, the zenithal distance of the meteor radiant; μ is the mass of the meteoric atom; H, D, and p are the height of a homogeneous atmosphere, the coefficient of diffusion, and the pressure at the height of the reflecting meteoric trail; and p_m is the pressure at the characteristic height h_m where evaporation reaches its maximum. The formula for the maximum of evaporation is

$$\Delta = \frac{16\pi^2 DR'^3}{v\lambda^3},$$

where v is the meteor velocity, R [illegible], r_0 is the initial radius of the ionized meteoric trail, t is the time span from the meteor passage of the middle of the first Fresnel zone, and q is a coefficient characterizing the increase of echo amplitude in the case of normal polarization of the electric vector. The formula of the signal power can be simplified under special conditions, as: parallel polarization, low diffusion, and small [illegible]. It is also possible to approximate individual parameters of the formula.

[Translation is available at the Library of Congress.]

6. A moving meteoric particle is heated to the burning point by friction in the upper atmospheric layers, and the evaporated atoms of the meteoric matter are ionized by collisions with air atoms. The ions and electrons produced form a plasma cloud in the air. V. P. Dokuchayev studied the scattering of the plasma path under the action of turbulent diffusion. The diffusion coefficient along the lines of the magnetic field increases in height, and the same coefficient across the lines diminishes from heights of 100 km and farther. The length of the meteoric path and the density of plasma are determined under the condition L cos $\chi \leq$ H, where L is the length of the path on which the ionization takes place, χ is the zenithal distance of the meteoric radiant, and H is the height of homogeneous atmosphere. By varying two parameters of the inequality, the third parameter can be determined. The equasion of diffusion is given in the form

$$\frac{\partial N}{\partial t} = D\left(\frac{\partial^2 N}{\partial r^2} + \frac{1}{r}\frac{\partial N}{\partial r} + \frac{\partial^2 N}{\partial z^2}\right),$$

where N is the concentration of plasma in one cm^3, D is the diffusion coefficient, r is the distance from the trajectory, and the coordinate Z coincides with the meteorite path. Transforming the equation by the aid of the Green function and the Bessel function of zero order with respect to the imaginary argument, an integral formula is obtained from which the final formula is derived:

$$N = [illegible] \left[[illegible] \operatorname{erf}(\beta_1) [illegible] \operatorname{erf}(\beta_2)\right],$$

where Q is the quantity of electron and ion pairs produced in a unit time, and

$$R_m = \sqrt{r^2 + (z - Vt)^2}, \quad \beta_1 = \frac{R_m + Vt}{\sqrt{4Dt}}, \quad \beta_2 = \frac{R_m - Vt}{\sqrt{4Dt}},$$

where V is the constant velocity of the source producing ionization:

$$\omega/c(\beta) = \frac{\sqrt{\pi}}{2}\,[1 - \Phi(\beta)]$$

This is a supplement to the error function $\Phi(\beta)$. $N(r, z, t)$ is analyzed for various distances and velocities from the path. On the basis of the analytical results, the author concludes that the maximum of plasma concentration is in the vicinity of the moving meteor. In the frontal side of the path, the concentration diminishes exponentially, and in the back side the decrease occurs smoothly.

[Translation is available at the Library of Congress.]

7. B. A. Mitrov studied the fast and slow molecules or atoms which depart from the meteor surface and form the initial trail. Two kinds of molecular streams which depart from the meteor are studied; slow "thermal" molecules which move with velocities of 1-2 km sec^{-1} and fast molecules which move faster than the meteor. The last molecules depart after elastic collisions with the meteor body. Both streams differ from each other by compounds. The slow molecules belong to the meteor matter, and the fast molecules are taken from the surrounding gas. Both streams carry energy which is able to form the trail effect. Trail intensity depends upon the inelastic collisions on the meteor body. The greater the probability of inelastic collisions, the more intensive is the trail. The initial trail width depends upon the distances to which molecules can depart from the meteor surface after the first impact on the surrounding matter.

The molecular motion from a moving meteor consists of two vectors: the vector of the meteor velocity and the vector of the proper motion of the molecule. The meteor velocity is V_m, and the slow thermal velocity of the molecule is V_T. The departure of a molecule from the meteor path is described by the author as a "withdrawal" and designated by λ^*. If λ is the distance travelled by the meteor during a time unit, the correlation between λ and λ^* may be written $\lambda = K\lambda$. K is given by an empirical formula:

$$K = \frac{V_T}{V_T + V_M}\sin^2\psi + \frac{V_T}{\sqrt{V_T^2 + V_M^2}}\cos^2\psi.$$

The angle ψ is determined by the formula

$$\operatorname{tg}^2\psi = \frac{\operatorname{tg}\varphi^2}{[illegible]^2 + \operatorname{tg}\varphi^2}$$

where φ is the angle between the vector of the meteor velocity and the vector of the thermal velocity of the molecule. The

maximum of trail width is reached when molecules depart from the meteor perpendicular to the meteor path. Some numerical samples are given for various velocities of a meteor and departing molecules.

In the beginning the formation of the trail occurs by imparting the molecular energy to the meteor body for evaporation. These molecules cannot depart far from the meteor path and form a narrow trail. Molecules of surrounding matter, after they are reflected from the meteor surface, form a wide trail enclosing the bright narrow one. A double trail may be observed in those upper atmospheric layers where the free passage in gas is sufficient for separating fast molecules from slow ones.

The great difference in K values of fast and slow molecules makes it possible to assume that atmospheric molecules are gathered in the outer part of the trail and reactions of these molecules cause the luminosity. The spectrum of the inner part contains both atmospheric and meteoric elements. The abrupt border between the two parts testifies to the fact that the process of diffusion is not developed.

[Translation is available at the Library of Congress.]

8. A. M. Furman developed a theory of ionization of meteor trails based on special parameters. The majority of the processes of ionization in the formation of meteor trails in the terrestrial atmosphere depend upon the ionization parameters of the meteor body. The parameters are: the work of electron departure φ_e, the work of ion departure φ_+, the potential of atom ionization U_i, and the evaporative heat of a neutral atom φ. These parameters vary during the motion of a meteor with the vigorous processes taking place on its surface.

A theory of ionization of a meteor trail is based on the study of parameter changes. The reasons for the work change during electron and ion departure are: 1) the change of chemical and structural composition of the meteor body by heating and evaporation of a fraction from its surface layers; 2) the continuous departure of charged and neutral particles; 3) a blowing off of particles from the meteor surface, thus hindering the formation of volumetric changes around the body of the meteor. Furman studied meteors which appeared and disappeared at heights where the free path of molecules is longer than the dimensions of the meteor body.

Very hot metallic bodies or melted metals emit four kinds of particles. They are neutral atoms (evaporation), electrons (electron emission), and positive and negative

ions (ion emission). These emissions are expressed by the formula

$$j_m = K_m T^n \exp(-\varphi_m / kT),$$

where j_m is the emission intensity of particles of m-kind. K_m is a constant of m-kind particle emission, T is the temperature in degrees Kelvin, φ_m is the evaporation heat of m-kind particles expressed in ev. Various kinds of emission are characterized by symbols: φ expresses the work produced in the departure of an electron from a metal; φ_+ and φ_- are the work produced by departures of positive and negative ions, respectively; and φ_a denotes the evaporation heat of neutral atoms. The mutual correlations of φ_m symbol values characterize the emission probability at a given temperature. These conditions are applied to individual emissions.

Meteoric bodies consist of chemical elements the specific weights of which are near the terrestrial elements. The following elements account for 98% of the weight of stony meteors: O, Si, Fe, Mg, Ni, Ca, Al, Na, P, K, Cr, Mn, and Co. Table 1 is a special table which contains data on the physical properties of these elements and is taken from Wright's paper [reference given]. The electron departure of the three alkaline elements Ca, Na, and K is connected with low input. A table contains characteristics of elements. It is emphasized that the oxides SiO_2, MgO, FeO, and Al_2O_3 also play an important role in particle emission when the lighter elements have evaporated. Elements with low input for electron departure remain until the total disappearance of the meteor because of their high melting and evaporation temperatures. Table 2 shows the input values expressed in ev for some oxides and their compounds. Inputs for simultaneous emissions of electrons and positive ions are computed. Their values are from 2 to 4 ev for stony meteors at temperatures from 3100 to 3400°K. The physical properties of elements and their compounds are given in Table 2. Table 2 shows that as a alkaline element Ca is found only in very small amounts in iron meteors and oxygen is not found at all in iron meteors. Oxides of alkaline metals need less input for electron and ion departure than pure metals, and their evaporation temperatures are high.

The author summarized the results obtained and emphasized the fact that the ionization abilities of neutral atoms and ions are different; this had not been taken into consideration in earlier investigations. A dynamic equilibrium exists between the intensities of different kinds of emissions. Meteor parameters are subjected to changes during the evaporation processes. Stony meteors preserve metallic oxides up to

high temperatures.

[Translation is available at the Library of Congress.]

Table 1

1	2	3	4	1	2	3	4
SiO_2	38.41	2000	2863	P_2O_5 и P	0.34	---	Возгонка ~632
MgO	23.66	3070	3870	MnO	0.23	>2000	--
FeO	13.60	1693	—	TiO	0.16	2098	—
FeS	5.18	1466	—	K_2O	0.16	—	—
Al_2O_3	2.86	2323	3250	CoO	0.06	—	--
CaO	1.88	2868	3123	Fe	9.06	1803	3270
Fe_2O_3	0.92	1838		Ni	1.09	1725	3070
Na_2O	0.82	—	--	C	0.16	380	4100
Cr_2O_3	0.4	2275	--	Co	0.16	1850	3073
NiO	0.4	2263	--	Cu	0.01	1356	2570

1 - Composition; 2 - weight, %; 3 - melting temperature °K
4 - evaporation temperature, °K.

Table 2

element	Contents, wt, %	Input for electron departure, ev	Melting temperature, °K	Boiling temperature, °K
Fe	88.8	4.36	1803	3270
Ni	9.5	4.84	1725	3070
Co	0.65	4.18	1850	3078
P	0.18	--	--	--
S	0.5	--	--	—
C	0.108	4.39	3800	4100
Cu	0.03	4.47	1356	2570
Cr	0.03	4.51	1890	2470
Mg	0.032	3.46	924	1340
Ca	0.05	2.76	1080	1770
Ti	0.01	4.09	[illegible]070	3275

9. A. M. Furman criticizes the Herlofson theory of the mechanism of ionization of meteoric trails. Disadvantages of the Herlofson theory are: 1) it cannot explain the ionization of micrometeoric trails; 2) basic reasons taken for proof are invalid; 3) the linear density of electrons and the brightness of meteors computed according to Herlofson's theory do not agree with observational data. The Herlofson theory covers only one of many possible explanations of the complex ionization mechanism of the meteoric trail; it is based only on the theory of atom evaporation from the meteoric body.

The ionization of meteoric trails depends upon the particles which collide with the meteoric body, some of which are reflected, absorbed, and evaporated. The ionizing ability of various atoms and ions evaporated from the body also depends upon the velocity at collision and the height of the place of collision. The incandescence of meteors starts at heights of 130 or 100 km from the earth's surface, depending upon the meteor velocity. Meteor temperature from 500 to 700°K causes emissions of thermoelectrons and thermoions. The input energy of electron emission varies when the evaporation of matter starts. It continues until a dynamical equilibrium between the electron and positive ion emissions is attained. Table 3 shows the input values at various meteor temperatures. The intensity of the thermoelectronic emission is determined by the formula

$$\frac{\delta n_0}{\delta t} = \frac{2}{e_0} \bar{D} A T^2 \exp(-\varphi^* / kT),$$

where $\delta n_0/\delta t$ is the intensity of electron emission from the surface unit of meteor, e_0 is the charge of an electron, $\bar{D}$ is the mean permeability of potential border on the meteor, A is a constant, T is the temperature in the Kelvin scale, φ^* is a balanced input in ev, and k is the Boltzmann constant. Setting $\bar{D} = 0.5$; $A = 120$ a cm^{-2} $grad^{-2}$, and $e_0 = 1.6 \times 10^{-19}$ coul; a new formula for computations is obtained:

$$n(T) = 7.5 \cdot 10^{20} T^2 \exp\left(-\frac{1.16 \cdot 10^4 \varphi^*}{T}\right) \frac{1}{\text{см}^2\,\text{сек}}.$$

where n(T) is the intensity of electron and ion emission from one cm^2 in one sec at temperature T. The ionization per cm of meteoric trail is expressed by the formula

$$a(T) = \frac{n(T)S}{V},$$

where V is the velocity in cm sec^{-1} and S is the meteor surface in cm^2. Table 4 presents a comparison of the tabular data with those obtained by Herlofson. It shows that the values obtained by Herlofson are smaller than those obtained by the author. Setting arbitrary values for the meteoric velocity, the radius of the meteor, and its surface, Furman determined the ratio

$$\frac{a(T)}{n(T)} = 2 \times 10^{-[illegible]}.$$

Upon penetrating into the terrestrial atmosphere, a meteor collides with air molecules. The collision energy

Table 3

Temperature intervals of meteor, °K	500	500 — 1200	1200 — 1500	1500 — 2000	2000 — 3123
Balanced input of electron and positive ion emission, ev.	1.26 — 1.4	1.4 — 1.77	1.77 — 1.81	(~1.96)	~2.0

Table 4

T°K	$\varphi^* = 0{,}7$ ev	$\varphi^* = 1{,}0$ ev	$\varphi^* = 1{,}77$ ev	$\varphi^* = 2{,}0$ ev	$\varphi^* = 2{,}25$ ev
	$n(T)$	$n(T)$	$n(T)$	$n(T)$	$n(T)$
500	$1.6\cdot10^{19}$	$1.5\cdot10^{16}$	—	—	—
750	$8.4\cdot10^{21}$	$8.4\cdot10^{20}$	—	—	—
1000	$2.4\cdot10^{23}$	$7.0\cdot10^{21}$		—	—
<1200	$<1.2\cdot10^{24}$	$<7.5\cdot10^{23}$	$<4.1\cdot10^{19}$	$<4.6\cdot10^{18}$	$<4\cdot10$[illegible]
1500	—	—	$2.5\cdot10^{21}$	$3.3\cdot10^{20}$	$4.9\cdot10$[illegible]
1750	—	—	$1.9\cdot10^{22}$	$4.1\cdot10^{21}$	$7.8\cdot10$[illegible]
2000	—	—	$8.5\cdot10^{22}$	$2.8\cdot10^{22}$	$6.7\cdot10$[illegible]
2250	—	—	$4.2\cdot10^{23}$	$1.3\cdot10^{23}$	$3.5\cdot10$[illegible]
2500	—		$1.3\cdot10^{24}$	$4.4\cdot10^{23}$	$1.4\cdot10$[illegible]
2750	—		$3.2\cdot10^{24}$	$1.2\cdot10^{24}$	$4.3\cdot10$[illegible]
3000	—	—	$7.2\cdot10^{24}$	$3.0\cdot10^{24}$	$1.1\cdot10$[illegible]

depends upon the mass of the meteor and its velocity. When the energy reaches 100—1500 ev, ionization by knocking out electrons, ions, and atoms is possible. At the height of meteor burn-up, viz, 130—75 km, the air density is low and the free passage of molecules is greater than the meteor dimensions. The number of collisions is sufficient for an ionization effect. The intensity of ionization by the kinetic knockout of electrons and ions from a solid body does not differ from the intensity of the process created by fast ions. The ionization intensity depends upon the probability of the process of inelastic collision α, upon the flow of Π air molecules colliding with the meteor, upon the surface and the compound of the meteor, and upon the collision energy E_o. The collision energy is characterized by the coefficient γ of the secondary electron emission as a function of E_o. The intensity of kinetic knockout dN_k is expressed by the formula

$$dN_k = \alpha\cdot\gamma\cdot\Pi\, ds,$$

where ds is the surface element, and $\Pi = nV$ where n is the concentration of air molecules and V is the velocity of the meteor. The coefficient γ of secondary electron emission represents a ratio of the number of emitted electrons to the number of colliding molecules.

In an earlier paper the author estimated the dependence of the elements of his theory upon the parameters of gas and metal by the formula

$$N / n = K_1 (V / B)^{10/14} \exp(- K_2 B^{6/7} / V^{10/7})$$

taking into consideration the law of collision forces

$$U(x) = B / x_0.$$

$$K_1 = (4\pi / 3)(\pi / 70)^{1/2} Q^2 C (2Q / \beta)^{1/2} (m / 2)^{10/14}$$

and

$$K_2 = (\beta / 2Q)(2 / m)^{6/7}.$$

These formulas are used for the computation of the ionization probability of molecular flow. A table of N/n values is given for arbitrarily taken velocities V. Formulas are given for a total number of negative ions

$$N_n = \alpha_1 S_1 n \cdot V,$$

where $\alpha = 0.5$ is the reflection coefficient and S_1 is the frontal surface of the meteor, and an ionization per a cm of path $a = \alpha_1 S_1 n$.

10. Ya. L. Alpert, A. V. Gurevich, and L. P. Piyayevskiy reviewed the study of the motion of artificial satellites in the plasmas of the ionosphere, of interplanetary space, and of cosmic or interstellar space. The distribution of neutral particles is determined by the following kinetic equation in a fixed coordinate system:

$$\frac{\partial f}{\partial t} + \mathbf{v}\frac{\partial f}{\partial \mathbf{r}} - \frac{1}{M}\frac{\partial U}{\partial \mathbf{r}}\frac{\partial f}{\partial \mathbf{v}} = 0.$$

The same equation in moving coordinates connected with moveing body is

$$\mathbf{v}\frac{\partial f}{\partial \mathbf{r}} - \frac{1}{M}\frac{\partial U}{\partial \mathbf{r}}\frac{\partial f}{\partial \mathbf{u}} = 0,$$

where f = f(r,v,t) is the function of distribution of neutral particles (molecules and atoms), M is the mass of particles, U = U(r,t) is the potential energy of particle interaction with the surface of the body, v is the velocity of particles, v_0 is the uniform velocity of the body, and u = v + v_0. Particles at great distances from the body are unperturbed and their distribution is subject to Maxwell's law.

The electrons and ions interact not only with the body, but with the electric and magnetic fields of the plasma as well. The distribution of particles under these conditions is expressed by the equations

$$\mathbf{v}\frac{\partial f_e}{\partial \mathbf{r}} - \left\{\left(1\frac{e}{m}\frac{\partial \varphi}{\partial \mathbf{r}} + \frac{1}{m}\frac{\partial U}{\partial \mathbf{r}}\right) - \frac{e}{mc}[\mathbf{H},\mathbf{u}]\right\}\frac{\partial f_e}{\partial \mathbf{u}} = 0$$

$$\mathbf{v}\frac{\partial f_i}{\partial \mathbf{r}} - \left\{\left(\frac{e}{M_i}\frac{\partial \varphi}{\partial \mathbf{r}} + \frac{1}{M_i}\frac{\partial U}{\partial \mathbf{r}}\right) + \frac{e}{M_i c}[\mathbf{H},\mathbf{u}]\right\}\frac{\partial f_i}{\partial \mathbf{u}} = 0,$$

where f_e(r,u) is the distribution function of electrons, f_i(r,u) is the distribution function of ions, e and m are the charge and mass of electrons, Mi the mass of an ion, φ = φ(r) is the potential of electric field, and H is the intensity of the magnetic field.

The distribution of particles depends upon the body velocity. The frontal side of the body is mostly vulnerable to impacts. Under such conditions the integral of the

distribution function takes the form

$$n(x, y, z) = \int f\left(x, y, u_x, u_y; \frac{z}{v_0}\right) du_x du_y$$

changing u_x and u_y into

$$x_0 = x - \frac{u_x}{v_0} z, \quad y_0 = y - \frac{u_y}{v_0} z,$$

and integrating, the perturbed molecular density is obtained:

$$\Delta n(x, y, z) = n_0 \frac{Mv_0^2}{2\pi kTz^2} \exp\left[-\frac{Mv_0^2}{2kT} \frac{x^2+y^2}{z^2}\right] \int_S dx_0 dy_0 \exp\left[-\frac{Mv_0^2}{2kT} \frac{x_0^2+y_0^2-2x_0x-2y_0y}{z^2}\right].$$

This formula is applicable to a body with a circular section. At very great distances, the disturbance changes approximately as $1/z^2$. Curves $n(\rho, z)/n_0$ show that a large region of rarified plasma is formed behind the moving body.

The integral of perturbed density, formed by a body of any cross section, yields

$$\Delta n = n_0 \frac{SMv_0^2}{2\pi kTz^2}$$

for very large values of z. This integral means that at large distances from the body, the disturbance decreases according to $1/z^2$.

In the frontal side of the body, particles accumulate and condense. This condensation can be formed by the mirror-like reflection which results when a surplus of particles equal to the number of particles colliding with the surface is created in a narrow volume dv_{zp}. The number of surplus particles is

$$n_2 = n_0 \frac{R_0^3}{\rho^3} \frac{\sin^2\theta_1 \cos^2\theta_1}{1 - \frac{R_0}{\rho}\sin^2\theta_1},$$

and the total number of particles in the frontal side of condensation is

$$n(\rho, z) = n_0 + n_2(\rho, z).$$

where ρ is the distance from the z-axis and R_0 is the radius of the cross section of the body. When $\rho \to 0$,

$$n_2(0, z) = n_0 \frac{R_0^4}{(2z + R_0)^4}$$

and the total number of particles

$$n(0, z) = n_0 \left(1 + \frac{R_0^2}{(2z + R_0)^2}\right).$$

The computed quantities of condensed particles show that near the body surface the number is twice as great as in plasma, and that at a distance of $2R_0$ the ratio $n/n_0 = 1.1$.

A diffuse reflection occurs from a rough surface. The supplementary density of particles is given by the formula

$$n_2(\rho, z) = n_0 \frac{R_0^2}{2\pi} \int_0^{2\pi} d\varphi_1 \int_0^{\arccos \frac{R_0}{\sqrt{\rho^2+z^2}}} \frac{\cos\theta' \sin\theta_1 \, d\theta_1}{\rho^2 + z^2 + R_0^2 - 2R_0\sqrt{\rho^2+z^2}\cos\theta_1} D(\theta'),$$

n_2 being analyzed at different distances from the body's surface. A significant increase of particles occurs in the case of accumulation.

The motion of the body under the action of the magnetic field is reduced to simple cases, and only the action of the author field is taken into consideration. The equations of ion distribution in a constant magnetic field are

$$\mathbf{v} \frac{\partial f}{\partial \mathbf{r}} + \frac{e}{cM_1} [\mathbf{v} + \mathbf{v}_0, \mathbf{H}] \frac{\partial f}{\partial \mathbf{v}} = 0$$

$$f_{z=0} = \left\{ \left(\frac{M_1}{2\pi kT}\right)^{3/2} \exp\left\{-\frac{M_1(\mathbf{v} + \mathbf{v}_0)^2}{2kT}\right\} \right.,$$

when the point is outside the cross section of the body, and $f = 0$ when the point is inside the cross section.

Characteristic of the distribution equations is

$$\frac{d\mathbf{v}}{dt} = \frac{e}{M_1 c} [\mathbf{v} + \mathbf{v}_0, \mathbf{H}], \quad \frac{d\mathbf{r}}{dt} = \mathbf{v},$$

The solution of the characteristic equation contains compli-

cated expressions for coordinates and velocities. The motion along magnetic lines causes the distribution of ions on the front side according to the final formula after some simplifications.

$$N_1(\rho, z) = 2N_0 \exp\left\{ - \frac{\rho^2}{\left(2\rho_H \sin \frac{\Omega_H z}{2v_0}\right)^2} \right\} \times \int\limits_{\frac{R_0}{2\rho_H \left|\sin \frac{\Omega_H z}{2v_0}\right|}}^{\infty} u e^{-u^2} I_0 \left(\frac{\rho u}{\rho_H \left|\sin \frac{\Omega_H z}{2v_0}\right|} \right) du,$$

where N_1 (ρ, z) is a periodic function depending upon the distance from the body.

The motion perpendicular to the force lines is mathematically very complicated. The function f also becomes complicated, and the distribution of ions for a body of rectangular section is

$$N_1(z, x, y) - N_{10} \quad \Delta N_1(z, x, y) = N_{10} - \frac{N_{10}}{4} \left\{ \Phi\left(\frac{x - R_x}{z} \sqrt{\frac{M_1 v_0^2}{2kT}} \right) - \Phi\left(\frac{x + R_x}{z} \sqrt{\frac{M_1 v_0^2}{2kT}} \right) \right\} \times \left\{ \Phi\left(\frac{y - R_y}{2\rho_H \sin \frac{\Omega_H z}{2v_0}} \right) - \Phi\left(\frac{y + R_y}{2\rho_H \sin \frac{\Omega_H z}{2v_0}} \right) \right\},$$

where Φ is the probability integral and

$$\rho_H = \frac{c}{eH} \sqrt{2M_1 kT}$$

The motion occurs in the direction of the z-axis; the magnetic field lines coincide with the direction of the x-axis. When $z \gg v_0/\Omega_H$, the influence of the magnetic field is strong.

A moving body destroys the quasi-neutral state of the plasma and creates an electric field in it. The electron density caused by elastic reflection around the moving body is given by the formula

$$N(\mathbf{r}) = N_0 \exp\left\{ \frac{e\varphi(\mathbf{r})}{kT} \right\}.$$

The equation of the electric potential is

$$\Delta\varphi(\mathbf{r}) = 4\pi e N_0 \left(\frac{N_i(\mathbf{r})}{N_0} - \exp\left[\frac{e\varphi(\mathbf{r})}{kT} \right] \right),$$

where

$$N_i(\mathbf{r}) = \int f_i \, d^3u$$

is the ion density, and N_0 is the unperturbed density of electrons. The distribution of electrons and ions is determined by transforming these equations and adapting them to different cases and shapes of bodies.

The dispersion of radio waves in the trace of a moving body in plasma forms a condensation of ions and electrons on the front and a rarefying on the back. The rarefied trace is larger than the wave length and the free path of particles. The dielectric permeability of plasma ε is given by the formulas

$$\varepsilon = 1 - \frac{4\pi N e^2}{m\omega^2}$$

and

$$\delta\varepsilon = -\frac{4\pi e^2}{m\omega^2}\delta N.$$

The theoretical formula of perturbations for various distances is

$$\mathbf{E}' = \frac{e^2}{m\omega^2\varepsilon} \frac{e^{ikR}}{R} [\mathbf{k}' [\mathbf{k}' \mathbf{E}_0]] N_{\mathbf{q}},$$

where E_0 is the amplitude of the incident angle: k' is the vector of the scattered wave ($k' = \sqrt{\varepsilon}\, \omega/c$); the Fourier component of perturbation of electron density,

$$N_{\mathbf{q}} = \int \delta N(\mathbf{r}) \exp(-i\mathbf{q}\mathbf{r})\, d^3r;$$

$$\mathbf{q} = \mathbf{k}' - \mathbf{k}, \quad |\mathbf{q}| = 2k \sin\frac{\psi}{2};$$

k is the vector of the incident wave; and ψ is the angle of scattering between k' and k. The Fourier component is discussed for various cases of scattering, and the function $F_3(\theta_2\varphi)$ is represented graphically.

The effective section of dispersion, when the magnetic field is absent, is expressed by the formula

$$\sigma(\theta) = \left\{ \frac{1}{16} \left(\frac{\omega_0}{c} \right)^4 \frac{R_0^6 \sin^2 \psi_1}{q^2} \right\} F(b_1, \theta) \Phi(qR_0 \cos \theta),$$

where

$$F(b_1, \theta) = \frac{\frac{\pi}{4} b_1^2 \exp(-2b_1^2 \cos^2 \theta) - [b_1 W(b_1 \ldots) \ldots] \ldots}{\frac{\pi}{4} b_1^2 \cos\theta \exp(-2 \ldots) \ldots [illegible]},$$

$$W(S) = e^{-S^2} \int_0^S e^{t^2} dt,$$

and

$$b_1 = \frac{M v_0^2}{2\kappa T}.$$

The function F(b,θ) is computed for three heights (300, 400, and 700 km) and represented in tabular form. The field of scattered waves which are generated by a moving body resembles a diffuse mirror reflection of the incident waves.

The particle flux in the vicinity of the body depends upon the shape and size of the body, the physical properties of the body surface, and the state of the particles. This is discussed for individual cases. The density of particles reflected from a sphere is determined by the formula

$$(\mathbf{nv})_2 = \int_0^{2\pi} d\varphi \int_0^{\pi/\alpha} \cos\vartheta \sin\vartheta \int_0^{\infty} v^3 \frac{d^3 r_1}{d^3 r} f_0(\mathbf{v} + \mathbf{v}_0)\, dv.$$

The density of particles in the backside can be expressed by an approximate formula:

$$(\mathbf{nv})_1 \approx \frac{n_0}{4\sqrt{\pi}} v_n \left(\frac{v_a}{v_0} \right)^2 \exp\left[-\left(\frac{v_0}{v_n} \right)^2 \right].$$

The interaction of the moving body with the plasma is connected with various effects. These effects must be taken into consideration for computations of the trajectories of artificial satellites and meteorological rockets.

11. B. Yu. Levin studied the fragmentation of meteoric bodies in the terrestrial atmosphere. This is one of the more important physical properties of meteors and one which makes it possible to estimate the resistance power of the upper atmospheric layers. The photometric curve of meteor brightness shows that the initial mass and its velocity do not play a role in the combustion process. This process depends only upon the parameter, μ, which characterized the evaporation power of the meteorite body. A correlation between the change of mass and the cross-sectional area of the body is given by the formula $S \sim M^{\mu}$.

The role of fragmentation can be evaluated by comparing the position points of the appearance and the disappearance of the same meteor with the theoretical curve drawn according to the formula $\Delta m = f(\Delta H)$, where Δm is the difference between the stellar magnitudes of the meteor in the beginning and at the brightness maximum and ΔH is the difference in height between the brightest state and the place of disappearance. The increase of stellar magnitude occurs faster under direct observation than is represented by the theoretical curve. The fragmentation shortens the meteor path and simultaneously increases the brightness.

The author introduces a parameter F to characterize the fragmentation. F is given in the form

$$F = \frac{L_{abs}}{L_{theor}} = \frac{(H_1 - H_2)_{abs}}{(H_1 - H_2)_{theor}}.$$

L_{abs} and L_{theor} are the real and theoretical path lengths. The brightness maximum of a meteor I_m is approximately equal to $M_O v_O \cos z$, where M_O and v_O are the initial mass and velocity of a meteor and Z is its zenithal distance at appearance. Levin determined the maximum of brightness from the formula $M_O v_O \cos z/F$. Using this value, the dispersion of points on the graph was lowered. The value of F is about one for meteors of low brightness. It was found to equal 0.2 for one very bright meteor.

12. During the IGY and IGC, meteor observations were carried out by K. A. Lyubarskiy and I. N. Latyshev at the Astrophysical Laboratory of the Physical and Technical Institute of the Academy of Sciences of the Turkmen SSR. Observations were made simultaneously from two bases, whose distance from each other satisfied the parallax claims and the expanse of sky. The meteor path was drawn on a stellar map noting the time observation, the stellar magnitude, the color, the velocity, and the trail.

The problem of telemeteors has been discussed in detail

by Soviet scientists, with differences of opinion. Bakharov (reference given) estimates the heights of telemeteors as equal to those of usual meteors. Astapovich and Terent'yeva (reference given) arranged telemeteor heights into four groups of 125, 95, 49, and 16 km. In the author's opinion, the great heights found for telemeteors result from erroneous methods of observations. Lyubarskiy and Latyshev criticize the observational method and processing procedure of Astapovich and Terent'yeva as being based on false assumptions and on a disregard of statistical rules.

The authors distributed the 195 parallaxes obtained into intervals of 5 arc min each and found the intervals in which most meteor paralaxes occurred. Intervals with many parallaxes were found at -5—0', and a further maximum was found at 12'.5. Histograms were drawn on the basis of the data obtained and the curves were smoothed, using Pearson differential equations. The average parallaxes of telemeteors are about 17' (arc min), which corresponds to the height of 101 km at the distance bases used. This height is equal to the heights of normal meteors.

The change in number of meteors of 9 stellar magnitude and fainter is represented graphically. The curve shows a decrease at midnight and an increase after midnight. The curve of parallax variations shows a periodic character which changes from season to season. The authors developed empirical formulas for parallax changes in summer and winter.

The influence of lunar tides on the meteoric parallaxes is studied. A table shows the dependence of the mean parallax of meteors upon the lunar hour angle. The parallax curve delays the lunar position by 3 hr. This delay is explained by complicated variations of density in upper layers of atmosphere.

Trail formation is found by Lyubarskiy and Latyshev in all observed meteors. The visibility of the trail depends upon instrument power. All meteors moving at high speed form trails. Trails of slowly moving meteors are unseen, and, in the authors' opinion, the slow meteors do not form a trail at all. The ionization processes depend more on the meteor velocity than on its mass. The trail contours are diffuse, and their state is dependent upon the degree of ionization.

The usual method of determining the velocities and directions of meteors is the "vector rose", which represents the velocity and direction by one vector. The authors reject this method and use the Öpik and Bakharov method based on the earth's apex direction. The earth's apex is computed for each meteor, and the meteor velocity and the azimuth

of arrival are [illegible] direction [illegible] distribution of meteor directions [illegible] the [illegible] is given in both tabular and graphic form. Velocities of meteors are determined from maps on which the path is plotted. The maximum of velocities occurs on paths coming towards the earth, but there is also a small maximum for the meteors overtaking the earth.

The radiants of each meteor were projected on the ecliptic plane. The projection showed that the majority of meteors are overtaking the earth. If the appearance of meteors is accidental, it is possible to apply Poisson's formula to telemeteors and to find theoretically the number of meteors in a given time interval. The authors computed this distribution and compared it with that obtained by observations. The agreement was good.

13. **N. A. Anfimov studied the conditions of meteoric motion in the atmosphere and the regularities of processes occurring during the motion.** Meteors gain luminosity with loss of matter at heights where the free path of air molecules l is comparable with the dimensions of meteoric body. The formula of Tsien (reference given) characterizes the region satisfying this condition as follows:

$$\frac{M}{\sqrt{Re}} > 0.01, \quad K < 10,$$

where K is the ratio of the free path of air molecules to the diameter of the meteor; M, a Mach number, is the ratio of meteor velocity to sound velocity; $Re = \rho VD/\mu$ is the Reynolds number which correlates the inertia forces with μ, the viscosity of air; ρ is the air density; V is the meteor velocity; and D is the diameter of the meteor.

The quantity of heat Q obtained during one time unit from one surface unit of the meteor is

$$Q = \Lambda \rho V^3/2.$$

If $K \gg 1$, then the coefficient of thermal conductivity Λ is constant and equal to the coefficient of accommodation. In the region of meteor gliding, Λ is a function of the Reynold's number and the parameter

$$\Lambda = \Lambda(Re, M/\sqrt{Re}).$$

It is impossible to determine Λ from direct meteoric observations. Anfimov used the parameter δ which is given by the formula

$$\delta = \Lambda/2G\zeta,$$

where G is the resistance coefficient and ζ is the energy

expended to separate one gram of meteor matter. The author used the following formulas for parameter computations:

$$\mathrm{Re} = \sqrt{\frac{\pi}{2RT}}\,\frac{V}{K};$$

$$\frac{M}{\sqrt{\mathrm{Re}}} = \sqrt[4]{\frac{2}{\pi RT}}\,\sqrt{\frac{VK}{\varkappa}},$$

where R is the gas constant, T is air temperature, and $\varkappa$ is the adiabatic index of air.

The air temperature and the free path are determined from rocket data for the height of meteor observations. The value of σ can be determined by comparing the results of observations with those computed theoretically, taking into consideration the evaporation by melting of meteoric matter.

Anfimov concludes that a fraction of the meteor matter is lost by evaporation. This assumption is based on the comparison of data observed with those computed theoretically and also on the dependence of σ upon meteor velocity.

[Translation is available at the Library of Congress.]

14. B. S. Dundnik, B. L. Kashcheyev, M. F. Lagustin, and I. A. Lysenko studied theoretically the reflection of radio waves scattered from the meteoric trail in the terrestrial atmosphere. The distance from the path element ds, from which the scattered wave is returned to the observer, is denoted by R. The length of the normal from the observer to the path is denoted by R_0. The formula of the signal received by the observer is

$$dE = E(R, \alpha_0)\sin\left(\omega t - \frac{4\pi R}{\lambda}\right)dS,$$

where α_0 is the linear density of electrons at the path and

$$\omega = \frac{2\pi}{\lambda}C$$

is the angular frequency of oscillations generated by the transmitter. The law of amplitude changes of the signal during the passage through the path element S may be found using the integral equation

$$E = E(R, \alpha_0)\int\limits_{(S)}\sin\left(\omega t - \frac{4\pi R}{\lambda}\right)dS.$$

$R^2 = R_0^2 + S^2$. S is small compared with . The integral equation can be transformed and solved according to Fresnel's integrals of optics. The final solution is

$$E = E_c (C_1 \sin \varphi - S_1 \cos \varphi).$$

The field E obtained is of a diffractional nature.

A special station was established for radar observations of meteors. This station operated at the wavelength 8.13 m with a pulse power of 75 kw; it was able to observe the diffractional picture of amplitude changes during 0.1 sec. The meteor velocity was determined by the formula

$$v = \frac{S}{t} = \frac{x}{2t} \sqrt{R\lambda},$$

x depends upon Fresnel's zones and upon R. $t = p/F$ where p is the number of pulses in the selected zone and F is the recurrence frequency

$$v = \frac{xF}{2p} \sqrt{R\lambda}.$$

The accuracy of v depends upon F and R. Numerical computations show that within the velocity range from 11 to 70 sec^{-1} and within R from 100 to 300 km, F must be taken equal to 500—600 cycles.

From 10 to 14 December 1957, radar observations of meteors were carried out by a special station in Kharkov. Each day, the maximum of meteor activity was observed from $0^h 00^m$ to $05^h 00^m$ of W. T. The maximum of recorded meteors during one hour was 200. Radiants for each meteor were not determined, and the positions of the sporadic Geminids could not be fixed. A histogram shows that the more frequent velocities were about 35 km sec^{-1}. The accuracy of the determined velocities depends upon the choice of Fresnel's zones.

[Translation is available at the Library of Congress.]

15. E. K. Nemirova studied the role of resonance effects for measurements of meteor velocities. The influence of resonance on the accuracy of meteor velocity is determined by the diffraction pulse method in which the wave is considered to be spherical. Following reflection of the meteor trail, Fresnel zones are formed with the center in the reflection point. The velocity v of the meteor is determined

by the formula

$$v \; [illegible]$$

where m and n are pulsation numbers, Δt is the time interval between two pulsations, and R is the distance to the reflecting point. This formula holds only for a cylindrical trail. The real trail is transformed into a rotational paraboloid by diffusion. The dispersion coefficient changes along the entire trail under the action of resonance in the ionized gas.

The resonance scattering of radio waves on meteoric trails takes place when the vector E of the incident wave is perpendicular to the trail axis (perpendicular polarization). The resonance is connected with an increase of intensity and a change of phase of the reflected wave. Parallel polarization appears when resonance is absent. The trail radius and the electron density indicate at what frequency the resonance may appear. The boundary of the Fresnel zones is determined by the points of the trajectory in which the reflected wave differs from other reflected waves by the phase $n\pi$ where n is an integer. Borders of Fresnel zones are shifted during the change of phase of the dispersion coefficient.

The degree of distortion in the diffraction picture depends upon the meteor velocity, the electron density, the diffusion coefficient, and the distance of the meteor. Nemirova computed the change of the diffraction picture for two cases of given parameters, used Fresnel integrals, and represented the results graphically. Numerical results show not only the change of intensity of reflected signals, but also a shift of the phenomenon in time and a change of the period and depth of pulsation. The distortion of the diffraction picture by resonance is determined using the basic ratio $l_{res}/\sqrt{R\lambda}$ where l_{res} is the length of trail where resonance takes place. When $l_{res}/\sqrt{R\lambda}$ is small, the distortion appears as a shift and a change of amplitude. When $l_{res}/\sqrt{R\lambda} > 2$, it is impossible to determine the velocity v.

[Translation is available at the Library of Congress.]

16. Ye. I. Fialko discussed the distribution of stable radio echoes received from normal reflection of radio waves. These reflected waves make it possible to determine the distribution of meteors according to their masses. The duration of reflection from a stable trail is given by the formula

where λ is the wavelength of radar, α is a linear electron density in the ionized trail, D is the diffusion coefficient, and $A_0 = 7.1 \times 10^{-15}$ cm. The linear electron density is determined by the formula

$$\alpha = \beta \frac{m \cos\chi}{\mu H} \frac{p}{p_m}\left(1 - \frac{1}{3}\frac{p}{p_m}\right)^2,$$

where β is the probability of ionization, m is the initial mass of the meteor; χ is the zenithal distance of the meteoric radiant; μ is the atomic mass of the meteor matter, H is the height of homogeneous atmosphere, p is the atmospheric pressure in the height of the reflecting trail, and p_m is the pressure at the characteristic height h_m.

$$p_m = \frac{Q}{v^2} m^{1/3} \cos\chi = \frac{2gQ'}{v^2}\left(\frac{9}{4} H \alpha_m \cos^2\chi\right)^{1/3},$$

where v is the velocity of the meteor, α_m is the maximum of linear electron density, $Q = 2lg/\Lambda A$ where l is the latent heat of evaporation, Λ is the coefficient of heat transfer, g is the gravity acceleration,

$$Q' = \frac{l}{\Lambda A}\left(\frac{\mu}{\beta}\right)^{1/3},$$

and $A = A_0/\delta^{2/3}$ where δ is the density of meteoric matter. The mass of the meteor is given by the formula

$$m = \left[\frac{v^2}{3Q\cos\chi}\left(p + 3.55 \cdot 10^7 \frac{\cos\chi}{v^2\lambda} \sqrt{\frac{Q^2 \mu H D \tau}{\beta p}}\right)\right]^3.$$

The distribution of meteors by their masses can be characterized by the function

$$f_m(m)\,\Delta m = \frac{b}{m^s}\Delta m,$$

where b and s are constants. The distribution of meteors by the duration of echoes is characterized by the function

$$f(\tau) = f_m(m)\left|\frac{dm}{d\tau}\right|.$$

The number of meteors causing a lasting echo in a time interval

$\tau + \Delta\tau$ is determined by the formula $N_1 = f(\tau)\Delta\tau\Delta S$, where ΔS is the surface area which reflects the radar echo. The same number of meteors can be expressed by the number of echoes. The final form of the function $f(\tau)$ is

$$f_c(\tau) = \frac{2}{h_2^2 - h_1^2} \int_{h_1}^{h_2} f(\tau, h)\, h\,dh.$$

If the reflection occurs from a stable trail, the distribution of radio echoes can be expressed by the function $f(\tau)$ of the form

$$f_c(\tau) = a_7 \int_{h_1}^{h_2} \frac{h\sqrt{HD/p}\,dh}{[p + a_2\sqrt{\tau}]^{3s-}}$$

where

$$a_7 = 3.9 \cdot 10^6 \cdot 3^{3s} b Q^{3(s-1/2)} \frac{(\cos\chi)^{3s-2}}{\lambda_b^{6(s-1/2)}} \frac{1}{h_2^2 - h_1^2} \sqrt{\frac{\mu}{\beta}}$$

These formulas hold true when the sensitivity of the apparatus is sufficiently high to be able to record each meteor which generates a strict quantity of electrons.

The number of recorded meteors $N(\tau)$ with the reflection duration exceeding τ is given by the formula

$$N(\tau) = N_1 \left(\frac{\tau_1}{\tau}\right)^{s-1}.$$

The accuracy of these formulas was checked by observational data of the Perseid meteor shower. The author sets $s = 1.5$, $N_1 = 190$, and $\tau = 4$ sec. The numberical value of the formula was

$$N(\tau) \approx \frac{380}{\tau^{0.5}}.$$

The graph of this function agreed with the experimental data.

[Translation is available at the Library of Congress.]

17. Kh. Gul'medov investigated the turbulence of upper atmosphere layers during the time of observation of meteoric paths and their development. The layer of terrestrial atmosphere from 70 to 110 km is denoted as a meteoric zone, because at those heights meteors are observed to burn up. The gas density, pressure, temperature, and winds of this

layer are determined from observational data of the meteoric path. In the beginning the path is seen as a bright and straight band, which decomposes later into many drifting layers of different thicknesses.

Photographs of four meteoric paths of the Orionid shower were obtained at Kazan in 1961. By processing observational data, the heights of three of these paths were determined. The initial height of path 1 was 110 ± 9 km, that of path 2 was 79 ± 10 km, and that of 3 was 109 ± 10 km. The velocity deviations from the average value amounted to 15—25 $msec^{-1}$. These deviations were caused by turbulent motions. The third path showed an oval-shaped condensation at a height of 96.5 km. This condensation moved along a circumference, the radius of which was about 10 km, with a translative velocity of 59 $msec^{-1}$. The mean velocities of the drifts were 56 ± 16 $msec^{-1}$ for path 1, 41.3 $msec^{-1}$ for 2 and 65 ± 16 $msec^{-1}$ for 3.

Formation of condensations was observed in all paths. The major axis of condensation was in the direction of the common flux. Wind gradients, which were very variable, are given in tabular form. The wind gradient of the third path is represented graphically by the author as depending upon the height. This graph was compared with the data from a French rocket and with a graph computed theoretically according to Kolmogorov's law. Neither the graph of the third path nor the path of the French rocket coincided with Kolmogorov's law.

18. I. V. Nemchinov and M. A. Tsekulin investigated the thermal transfer to the body and the loss of its mass for big meteorites moving at high speeds. Meteorites of large mass make it possible to concentrate the investigation on low heights where the physical processes are known. High meteoritic velocities may be associated only with the radiative transfer of heat, because the opaque vapor layer is heated to a high temperature which approaches the temperature at the front of the shock wave. The shock wave makes the thermodynamical and optical properties of the air similar to those of other gases, and also the properties of different meteorites play an insignificant role. The shock adiabates for various heights are taken from Selivanov and Shlyapintokh's book [reference given] in which the effective adiabatic index k is computed by using the formula

$$e = \frac{p}{\rho} \cdot \frac{1}{k-1}.$$

The shock adiabate is computed by means of the formulas

$$p_s = \frac{2}{k_s+1}\rho_n D^2, \quad \frac{u_s}{D} = \frac{\rho_s}{\rho_n} = \frac{k_s+1}{k_s-1} = \gamma_s,$$

where D is the velocity of the shock wave, u_s is the velocity of gas related to the front of the wave, p_s is the pressure, ρ_h is the density of the air before the front, and γ_s is the compression (s is associated with the frontal part). Using these formulas, the compression, the number of lost air electrons, the adiabatic index k, and the inner energy e of a mass unit were computed for some cases and given in tabular forms.

The authors found that at heights of 30 to 50 km the gas is opaque behind the front of the shock wave when the dimensions of the body are sufficiently large. The radiative thermal transfer behind the front is determined by the criteria

$$B = A\lambda = \frac{\sigma T_s^4}{1/2\rho_n D^3}\frac{l_s\gamma_s}{R}.$$

and

$$A = \sigma T_s^4 / \tfrac{1}{2}\rho_n D^3$$

When radiative thermal transfer is very small, the zone in which this transfer takes place is less than the dimensions of the body. The gain of heat in a small zone before the front compensates for the heat loss behind the front. The gas of a density from 10^{-2} to 10^{-3} becomes transparent when heated by the shock wave. At the surface, where air and the meteor vapor meet, both gases spread into one thin layer parallel to the surface. The energy equation at a constant pressure is

$$\chi \frac{dh}{d\psi} + \frac{dq}{d\psi} = 0$$

where h is the enthalpy of the air and vapor, χ is the consumption of gas mass in the direction of the axis of symmetry (χ is positive for air and negative for vapor), q is the flux of radiative heat, and

$$\psi = \int_0^x \rho dx).$$

The enthalpy is a function of the pressure and temperature, and χ is a function of the density and velocity of gas.

Numerical values of effective adiabatic index and the number of free electrons of aluminum and iron are given for various temperatures. These values are taken from the C. A. Rouse tables [reference given]

A sharp change of temperature and density occurs near the surface of sublimation. This phenomenon is caused by the nonlinear form of the coefficient of thermal conductivity. The remainder of vapor mass has a temperature similar to that behind the front of the shock wave.

Departure of masses from a unit surface and during a unit time is given by the formula

$$\frac{dm}{dt} = \alpha_0 \rho_0 D,$$

where α_0 is the proportionality coefficient and ρ_0 is the air density on the ground surface. The coefficient α can increase with a decrease of density.

19. K. N. Alekseyeva and K. A. Tovarenko determined the dielectric constant and the electric properties of meteorites. The electric conductivity of plates cut from meteorites was investigated. The following meteorites were studied: 1) the Yelenovka meteorite, a friable chondrite consisting of olivine, pyroxene and 12% ore-bearing minerals in the form of metallic chondrules; 2) the Pinto Mountain meteorite, a crystalline chondrite containing olivine, pyroxene and approximately 8% ore-bearing minerals; and 3) the Norton County meteorite, a friable achondrite containing enstatite, olivine and a very few ore-bearing minerals.

The specific volumetric electric conductivity of the Yelenovka meteorite was 8×10^{-6}; that of the Pinto Mountains meteorite was 7×10^{-9}, while that of the Norton County meteorite was 1.3×10^{-8}. The specific electric conductivity of ultrabasite was 3×10^{-8} cm ohm^{-1}. The dielectric permeability of the Yelenovka meteorite was -49; of the Pinto Mountain specimen, -14.3; of the Norton County specimen, -15; and of the ultrabasite, -20.

A direct relationship between the dielectric permeability and the electric conductivity is evident from a comparison of measurement data. A high dielectric permeability and a high electric conductivity are both caused by the content of metallic inclusions. Meteorites, according to their properties, are magnetodielectrics because of their high Fe and Ni content. The magnetodielectric nature of meteorites was stated by the authors in a previous paper (reference given) which was concerned with investigations of the magnetic properties of meteorites. Meteorites have a high magnetic

susceptibility and residual magnetization. These electric and magnetic properties of meteorites are believed to be important for stydying the behavior of meteoric matter in space.

20. V. G. Fesenkov considers meteorites to be fragments of asteroids with direct motion along their orbits. Meteorites can overtake the earth, or the earth overtake them, depending on their orbital velocity. The collision velocity is the difference between the velocities of the earth and the meteorite. A big meteorite can reach the earth's surface in the form of a stone or stony fragments because the kinetic energy of the meteorite under the friction conditions in the terrestrial atmosphere is not sufficient to destroy it entirely.

Comets can have direct or retrograde motion. In the latter case velocities are summed, and the kinetic energy of the comet results. Both the core and the tail of a comet consist of small particles which ionize the terrestrial atmosphere and burn off because of atmospheric friction.

The motion of the Tunguska meteorite was retrograde: it could, in fact, have been a comet colliding with the earth. Powerful phenomena in the atmosphere, an anomalous twilight on the day of collision, great disturbance of the geomagnetic field, and the pollution of the atmosphere with dust after the collision substantiated the cometary nature of the Tunguska meteorite. This meteorite is also believed to have been a comet because no trace of stony fragments was found.

21. I. T. Zotkin described anomalous light phenomena associated with the fall of the Tunguska meteorite, which were observed in the terrestrial atmosphere in the USSR and other European countries. Publications in scientific journals and newspapers and other data possessed by the Committee on Meteorites at the Academy of Sciences of the USSR were used as sources for the description.

On the night of 30 June-1 July 1908 an anomalous red twilight, intense noctilucent clouds, and a very strong enhancement of night sky brightness were observed in European Russia, Poland, Austria, Hungary, Germany, France, Belgium, Holland, Great Britain, and Ireland. Anomalous twilights were also observed in some parts of Asiatic Russia. No anomalous phenomena were noted in America. The northern limit of regions with anomalous atmospheric phenomena was determined from the latitude parallels of white nights which prevented observations. The western boundary of the region of anomalous phenomena passed through Ireland, the southern boundary, along a great circle extending from Brittany to the Northern Caucasus. The eastern boundary could not be defined.

The author suggested that the phenomena observed could not be caused by dust masses lifted to heights of several

hundreds of kilometers from the earth's surface. He believes that dust particles entered the atmosphere from outside, apparently in the form of a cloud of atomized matter from the envelope and nucleus of a comet.

22. G. I. Pokrovskiy studied mechanical phenomena in the motion of meteoric bodies in the terrestrial atmosphere. The braking effect of the atmosphere depends upon the length of the free path of eroded meteoric particles in atmosphere, especially when the free path exceeds in length the dimensions of the meteor. Sometimes the erosion of a meteoric body can cause a decrease rather than an increase in atmospheric resistance. Under some conditions, forces developed by erosion can even favor the acceleration of the meteor.

Forces produced by a change of momentum of the resisting medium are represented by the formula

$$F = \theta \sqrt{2M_1E_1},$$

where M_1 is the loss of mass in one unit of time, E_1 is the energy change of the mass, and θ is the coefficient expressing the energy distribution in the mass M_1. When the energy distribution is uniform, $\theta = 1$; with an increase in heterogenity, θ decreases. The author analyzed the case when the lost matter is ejected in a direction opposite to the motion of the trace. In this case F is an accelerating force. The energy gained by the meteor from resisting air at the frontal part is represented by the formula

$$E_{1e} = \alpha \frac{C_x}{2} \rho v^3 S,$$

where C_x is a coefficient of the frontal resistance, ρ is the air density, v is the velocity of the meteor, S is the cross section of the meteor, and α is the coefficient of energy transfer to the meteor body

The loss of mass in a unit of time is equal to

$$M_{1e} = \frac{E_{1e}}{Q_{1e}},$$

where E_{1e} is the energy consumed by erosion and Q_{1e} is the specific energy used in the decomposition of the meteoric mass. These values of M_{1e} and E_{1e} are set in the formula for F, and its maximum is analyzed.

The meteor may be spherical in shape and may rotate. The axis of rotation may be perpendicular to the direction of motion. The heated front side of the meteor receives energy which erodes the meteor matter. Ejected particles are transferred to the trail side by the rotating meteor. Various kinds of meteors are studied theoretically, and cases when F acts as an accelerating force are discussed.

The action of exploding gases on the shock wave of air is discussed. The shock wave propagates rapidly in a hot trail, losing its shape. An increased shock-wave velocity creates additional energy in the back side of the meteor. The active zone on the front side is a hemisphere and on the back side, a rotating ellipsoid. The action of a shock wave was checked by laboratory experiment. Because of defects in the experiment, the existence of a distinct ellipsoid-shaped shock wave on the back side was not proven although an increase in the radius of the back side was observed.

23. K. P. Stanyukovich and V. P. Shalimov studied the motion of a meteoric body in the terrestrial atmosphere in one of two ways, depending upon the length of the free path λ of air molecules compared with the dimensions of the meteoric body r. When the free path is very large as compared with the dimension ($\lambda \gg r$), it is possible to study collisions of individual air molecules with the meteor. Collisions cause a braking effect which leads to the destruction of the body and an increase in the surface temperature. The free path of molecules is short in the lower atmospheric layers ($\lambda < r$). In this case the high velocity of the meteor favors the formation of shock waves. Hydrodynamic methods associated with solid media may be used to study this kind of motion. A table of densities and the lengths of free paths for various heights is given in the original article, from which it can be deduced that the formation of shock waves takes place at a height of 80 km.

Each air molecule, on colliding with a rapidly moving meteorite, takes many atoms and molecules from its crystal lattice. The meteoric surface ejects not only evaporated mass but also fragments of the lattice. The author gives the following system of equations of impulse and energy conservation:

$$d(Mu) \quad u_1\,dm \quad u_2\,dM$$

$$d(Mu^2) \quad u_1^2\,dm \quad 2dE \quad u_2^2\,dM.$$

where M is the mass of a meteorite, m the mass of air molecules, u is the velocity of the meteorite, u_1 and u_2 are the velocities of reflected air molecules from the meteorite surface and the extracted particles of crystal lattice, and

U_1 and U_2 are projections of these velocities on the flight direction of the meteorite.

The evaporation of the crystal lattice ceases when

$$\frac{1}{2}\left(\frac{u_k}{1+\alpha}\right)^2 = \varepsilon_k,$$

where ε_k is the energy density of evaporation,

$$\chi = \frac{\mu_a}{\mu} \cdot \frac{\mu}{a}$$

is the molecular weight of air, and μ is the molecular weight of the lattice. The evaporated mass $M_1\varepsilon_k$ is equal to

$$M_1\varepsilon_k = \frac{m}{2}(u^2 - u_k^2)$$

or

$$M_1 = m\left[\frac{u^2}{2\varepsilon_k} - (1+\alpha)^2\right].$$

The energy of gas produced is described by the formula

$$E_g = m\left\{\frac{C_v}{\mu}T + \frac{u^2}{2}(1+\alpha)^2 + (1+\alpha)^2\varepsilon_k\right\}.$$

The total mass of the crystal lattice is denoted by M_t. Energy expended on the decay of the lattice is

$$\Delta E = \eta(M_t - M_1)\varepsilon^*;$$

η is a factor which indicated the fraction of the energy which is irreversibly spent for deforming the lattice $\eta < 1$.

The velocity of particles scattered from the evaporated lattice is expressed by the formula

$$\frac{V_{2t}^2}{2} = \bar{\varepsilon} - \frac{C_v T_1}{\mu} \cdot \frac{(1+\alpha)^2\varepsilon_k - \frac{C_v T}{\mu}}{1 + \frac{u^2}{2\varepsilon_k} - (1+\alpha)^2},$$

where $V_2 = u_2 - u$. The loss of the meteorite mass is expressed by the formulas

$$dM = -dm\, f(u)$$

and

$$f(u) = \frac{1}{1+\eta}\left\{\left[\eta + \frac{C_p T_1}{\mu \varepsilon^*}\right]\left[\frac{u^2}{2\varepsilon_k} - (1+\alpha)^2\right] + \frac{\varepsilon_k}{\varepsilon^*}(1+\alpha)^2 - 1\right\}.$$

Transforming the equations of impulse and energy conservation by means of these formulas for mass loss and for velocities of scattered particles, the drag coefficient C_x may be determined by means of the formula

$$C_x(u) = 2\left[\frac{u_1}{u} + \left(\frac{u_2}{u} - 1\right) f(u)\right] = C_x = 2\left[1 + \frac{\varkappa^* \varkappa}{u}(V_1 + V_2 f(u))\right].$$

The drag coefficient is computed for various velocities of meteorites.

The shock wave is formed when the free path of air molecules is less than the dimensions of the moving meteorite, and when the heated meteorite surface ejects evaporated and crushed particles. The temperature of the ejecting surface is much lower than the temperature of the shock wave front T_y. The dependence of the shock wave temperature T_y on the ejection velocity u_p is expressed by the formula

$$\frac{C_1}{\mu} T_y = \frac{u_p^2}{2},$$

where μ is the molecular weight of air. The radiative emission of a hot surface and of the shock wave were compared on the basis of the Stefan-Boltzmann law

$$\frac{L_y}{L_b} = \left(\frac{T_y^4}{T_b^4}\right)$$

Having determined numerical values for both temperatures, the ratio $E_{1y}/E_{1b} = 6^4$. The radiative surface of the shock wave is larger than the meteorite surface. This condition attests to the very high destructive action of a shock wave.

The momentum of a meteorite under a strong braking effect which causes evaporation is represented by the formula

$$M\frac{du}{dt} = -\frac{1}{2}C_x S \rho u^2 + k V_t \frac{dM}{dt},$$

where M is the mass of meteorite, u its velocity, S is a cross section of a meteorite, ρ is the air density, V_t is the mean velocity of evaporated particles, and K is the coefficient of spatial distribution of evaporated particles. This coefficient is equal to 2/3 for a plane and 4/9 for a spherical space:

$$\frac{dM}{dt} = -\Sigma m N,$$

where Σ is the meteorite surface, m is the mass of a meteorite molecule, and N is the rate of evaporation from one cm^2 per second. $N = f(T)$. These two formulas are transformed, and numerical values are used for some parameters. By means of these operations the meteoritic velocity is found for various heights using the formula

$$V = \exp\left\{-a^* \int_0^{\xi} \frac{d\xi}{\eta(\xi)}\right\},$$

where

$$V = \frac{u}{u_0} \qquad a = \frac{3}{8}\frac{C_x H^*}{\delta \cos\varphi}; \quad a^* = a\frac{\rho(H_0)}{r_0}, \quad \xi = \frac{\rho}{\rho(H_0)}; \quad \eta = \frac{r}{r_0};$$

ρ is the angle between the normal to the atmosphere and the trajectory of the meteorite, and H_0 is the height at which the shock wave occurs. These formulas are applied to various atmospheric densities, and approximate calculations are made with arbitrary numerical values. The air radiation, after the air has been heated by a snock wave, plays an important role.

24. V. A. Bronshten studied the motion of the Tunguska meteorite in the terrestrial atmosphere using Fesenkov's method. Equations of motion are expressed by the system

$$m\frac{dv}{dt} = -\Gamma S\rho v^2,$$
$$\frac{dm}{dt} = -\Lambda\frac{S\rho v^3}{2Q},$$

where m is the mass, v the velocity, S the mean cross section of the meteorite, Γ and Λ are coefficients of resistance and heat transmission, ρ is the air density, and Q is the heat quantity expended for heating and evaporation of the meteoritic matter. Fesenkov assumed that the mass decrease stops not at zero velocity, but a little earlier, at v = a. He completed the last equation with a multiplier

$$\frac{v^2 - a^2}{v^2}: \quad \frac{dm}{dt} = -\Lambda\frac{S\rho v^3}{2Q}\cdot\frac{v^2 - a^2}{v^2}.$$

A solution of this equation is

$$\frac{m}{m_0} = \left(\frac{u}{u_0}\right)^{-3u_0\frac{a^2}{v_0^2}} e^{-3(u_0 - u)}.$$

A solution of the first equation of the system is given in the form

$$\left(\frac{u_0}{u}\right)^{\frac{\sigma a^2}{6}} \int_u^{u_0} e^{-(u_0 - u)}\frac{du}{u} = \frac{2\Gamma A\rho_0 H \sec i}{m_0^{1/3}} e^{-h/H},$$

where

$$A = \frac{S}{m^{2/3}},$$

i is the angle formed by the trajectory and the vertical, H is the height of the homogeneous atmosphere, and $\delta = \Lambda/2\Gamma Q$. The change in atmospheric density is determined by the barometric formula

$$\rho = \rho_0 e^{-h/H}.$$

Transforming the last formula and introducing a constant multiplier M, the height h is found. The height h is proportional to the ratio of masses and velocities m/m_0 and v/v_0:

$$h = -18{,}45 \lg \frac{1}{M} \int_x^1 \left(\frac{m}{m_0}\right)^{1/3} \frac{dx}{x}.$$

The parameters σ, Γ, Λ, and A are taken from publications of Western scientists. The drag coefficient C_x is determined by means of the formula

$$C_x = 2\Gamma = \frac{2}{3} \frac{8+\pi}{\sqrt{\pi}} \sqrt{\gamma - 1},$$

where γ is the adiabatic index of the air.

The parameters of the Tunguska meteorite are taken as $\gamma = 10^{-12}$, $A = 0.6$ $i = 80°$, $a = 10^5$ cm/sec, $H = 8 \times 10^5$ cm, $\rho_0 = 1.25 \times 10^{-3}$ g/cm^3. The initial mass of the meteorite is estimated to be 10^5, 10^6, or 10^7 tons. The terminal velocity and mass are arbitrarily determined, from which many variants are derived. The temperature and energy are determined from these variants, and numerical values are given in tabular form. Graphs of terminal mass, velocity, and the change of mass and velocity in the atmosphere are represented with respect to the height above the earth. Only those variants are taken which satisfy the probable energy for damage at the place of impact. The initial mass is taken to be $10^5 < m_0 < 10^7$ tons, and the terminal mass is $2 \times 10^4 < m$ 7.5×10^4 tons. The initial velocity is taken to be $28 < v_0 < 40$ km/sec, and the terminal velocity is $16 < v_t$ 30 km/sec. A more accurate solution is impossible at present because of the very limited data on the impact conditions.

25. M. A. Tsikulin studied the forest destruction caused by a ballistic shock wave reflected from the earth. The action of a shock wave is compared with the destruction of an explosion of a cylindrical charge with the energy q_1. The destructive action of a shock wave is evaluated by the product $\rho_1 u^2$, where ρ_1 is the density and u is the velocity of the gas behind the front of the shock wave. The forest destruction is recognizable in a zone around the point of the

wave reflection. Critical values of $\rho_1 u^2$ at which destruction is possible are $\rho_1 u^2 \geqslant 150 \pm 30$ kg-m^{-2} for minor destruction and $\rho_1 u^2 \geqslant 500 \pm 50$ kg-m^{-2} for extensive destruction.

The author developed an empirical formula for the pressure at the front of the shock wave:

$$\frac{\Delta p}{p_0} = \frac{0,24}{\xi^2} + \frac{0,48}{\xi^{3/4}},$$

where $\xi = r/\lambda$ is an abstract parameter, r is the distance from the explosion line, and $\lambda = \sqrt{q_1/p_0}$ is the characteristic rate of cylindric explosion, q_1 is the energy of explosive matter per unit length, and p_0 is the atmospheric pressure.

Fixing numerical values for parameters, the energy q_1 is determined to be equal to (1.0 to 1.6) x 10^{17} rg cm^{-1}. The inclination α of a tangent to the meteorite trajectory to the earth's surface is expressed by the formula

$$\alpha = \frac{dr}{dz} = \frac{M}{M_a},$$

where r and z are coordinates, and M is the intensity of the shock wave at the point in question. The inclination α_0 at the moment when the shock wave touches the earth's surface is equal to

$$\alpha_0 = \frac{M_0}{M_a}.$$

where M_0 is the shock wave intensity at the epicenter:

$$M_0 = \sqrt{1 + \frac{0,20}{\left(\frac{h}{\lambda}\right)^2} + \frac{0,41}{\left(\frac{h}{\lambda}\right)^{3/4}}}$$

where h is the height of the trajectory above the epicenter. Formulas for shock-wave intensities are given for destruction zones. Using these formulas and establishing numerical values for parameters, approximate solutions for velocity, trajectory height above the epicenter, meteoritic diameter, its mass in tons, and its density were obtained. The total energy of the meteorite delivered over the zone of destruction was estimated to be (2 ± 0.5) x 10 ergs. A more precise solution of this problem is impossible. The mechanism of explosion was checked by a model experiment wherein the bolide was simulated by the explosion of a detonating fuse stretched over a plane; trees were represented by small rods. The experimental results were positive.

26. B. Yu. Levin. Physical Theory of Meteors and Meteoric Matter in the Solar System consists of two parts which in turn are divided into six chapters each containing 28 sections. The first part of the book deals with problems of physical theories of meteors. This part contains three chapters devoted to investigations of the phenomenon of motion in the terrestrial atmosphere.

Chapter I contains an introduction and a history of the development of the physical theory of meteors, the fundamental equations of the motion and heating of meteors, and the probable structure of the atmosphere.

Chapter II deals with the motion of meteors in the upper atmospheric layers where they collide with air molecules. The braking and pulverizing actions of the upper atmospheric layers on the meteoric body is discussed. The heating of meteoric bodies is treated theoretically, using adapted formulas.

Chapter III deals with processes of intensive evaporation of a meteoric body. The beginning of pulverization and evaporation of a meteoric body is developed theoretically and treated for both large and small bodies. Numerical values for the resistance coefficient and the coefficient of thermal conductivity are determined theoretically and expressed numerically in some cases. The correlation between velocity and loss of mass is discussed. The brightness of meteors is discussed theoretically.

The second part of the book deals with meteoric matter and its origin in the solar system. This part contains three chapters in which the origin and development of meteor showers, their density, and the number of meteor streams in space are discussed.

Chapter IV deals with the origin and development of meteor swarms in space. The relationship between meteor swarms and comets is presented statistically, and the influence of planetary perturbations on the disintegration of comets is discussed.

Chapter V deals with the spatial density of meteor swarms in space and meteor showers observed on the earth. An attempt is made to determine the quantity of meteoric matter delivered to the earth during a shower.

Chapter VI deals with the origin of sporadic meteors. The brightness of ordinary and telescopic meteors is discus-

sed. The radiants of sporadic meteors are compared with the radiants of meteor swarms which are the source of sporadic meteors. A special section is devoted to meteor swarms which accumulate near the earth's orbit in space. The book covers all aspects of meteoric phenomena in space which are observed from earth. More than 300 Soviet and Western references are given.

27. V. V. Fedynskiy. Meteors is a popular-type book for nonspecialists. It contains 10 sections dealing with the development of meteor theories, modern methods of meteor investigations, and the study of meteor flight in the terrestrial atmosphere. The use of meteor observations to study the structure of the upper atmosphere is discussed. Meteoric matter in the solar system, meteor showers, and interstellar dust are described.

28. L.A. Katasev. Photographic Methods in Meteor Astronomy is a book divided into 9 chapters dealing with the photography of meteors and the processing of photographs.

Chapter I contains a description of the instruments used in meteor photography and the methods for measuring photographs.

Chapter II deals with radiant determinations and the study of the translocation of radiants on the sky with time.

Chapter III includes methods of meteor altitude determination. Bessel's criterion and the formulas of Fedynskiy and Stanyukovich are discussed. Stanyukovich's method for determining meteor orbits in the terrestrial atmosphere is given, and the choice of basic method for meteor observations is discussed.

Chapter IV deals with the determination of meteor velocities by visual and photographic methods. A table of velocities of meteor showers is given.

Chapter V deals with the brightness of meteors and the methods of determining their visual and absolute stellar magnitudes.

Chapter VI deals with the studies of spectral lines of meteors and estimations of their chemical composition.

Chapter VII deals with mathematical theories of physical phenomena observed in the atmosphere during meteor flight. Equations of motion are given from which meteor mass may be determined. The meteorological properties of the upper atmosphere are discussed, on the basis of data derived from meteor observations.

Chapter VIII deals with formulas for orbit determination and the orbital elements of various meteor showers.

Chapter IX deals with correlations of meteors and other heavenly bodies and the origin of meteoric matter in space.

This book is a good concise review of methods of observing meteors and processing observational data. It is based on Soviet and Western publications (106 references are given).

29. I. S. Astapovich. Meteoric Phenomena in the Earth's Atmosphere contains 35 chapters, covering, in descriptive form, various meteoric phenomena in the terrestrial atmosphere, starting from prehistoric time and ending with modern methods of observation and theoretical conceptions of the nature and origin of meteors.

Chapter I deals with the historical development of conceptions of meteors in various cultures.

Chapter II deals with the history of scientific studies of meteors in ancient Greece, China, Arabia, and Europe.

Chapter III contains a description of the structure of the terrestrial atmosphere and the physical phenomena in it.

Chapter IV deals with the optical properties of the observer's eye and its sensitivity to brightness intensity and motion perception.

Chapter V deals with astronomical, geophysical, and geometric conditions favoring or hindering meteor observations. The psychological state of the observer during meteor observations is discussed.

Chapter VI contains a classification of meteors according to their brightness, mass, and velocity.

Chapter VII deals with methods of studying meteors, such as the photospectrographic, the colorimetric, the photoelectric, the magnetic, the electric, and the radar method.

Chapter VIII deals with visual and telescopic methods of meteor investigations.

Chapter IX treats photographic methods of meteor studies.

Chapter X discusses radiophysical investigations of meteors and the use of meteors for radio communication.

Chapter XI deals with the number of meteors in a shower and the number of diurnal and annual meteor quantitative

variations. The activity index and meteor density are given.

Chapter XII treats the radiants of meteor showers and methods of determining them. The distribution of meteoric trajectories is discussed.

Chapter XIII deals with altitudes of meteors and methods of determining them. Bessel's criterion and Olbers' principle are discussed. The altitudes of various meteor showers are given.

Chapter XIV deals with meteor velocities and methods of determining them. Both the cosmic and galactic velocities are discussed. The velocities of some meteor showers are given.

Chapter XV deals with the forms of trajectories and the methods of determining them.

Chapter XVI discusses the brightness of meteors. The absolute meteor brightness and the distance module are explained. Curves of brightness variation are discussed.

Chapter XVII describes meteor spectra and methods of determining them. Correlations between the spectra of meteors and of comets are discussed.

Chapter XVIII deals with color, temperature, and thermal radiation of meteors. The classification of meteors by color and by color variation is discussed.

Chapter XIX deals with the size and shape of meteors. The structure of meteors is discussed.

Chapter XX treats the rotation of meteors. Procession and nutation of the rotation axis are discussed.

Chapter XXI deals with meteor crushing and meteoric complexes formed by many bodies. Bolides and meteoric accumulations are described.

Chapter XXII deals with the braking effect of the terrestrial atmosphere on meteor motion. Equations of the braking effect and methods of determining it are discussed. Formulas for preatmospheric velocity are given.

Chapter XXIII deals with motion in a resisting medium. Meteor motion in the terrestrial atmosphere is described.

Chapter XXIV deals with the physical theory of meteor properties.

Chapter XXV deals with the determination of mass in meteoric bodies.

Chapter XXVI deals with ionization processes and explosions of meteors. The appearance of meteors in auroras is described.

Chapter XXVII deals with the gaseous trails of meteors. The brightness brightness and duration of trails are described.

Chapter XXVIII deals with electromagnetic phenomena occuring during meteor flight in the atmosphere. Ozone formation and radio emission from meteors are described.

Chapter XXIX deals with colides and their dust trail. The trajectories of colides and a description of their trails are given.

Chapter XXX deals with meteor falls. Motion in the resistant atmosphere, especially in the lower atmospheric layers, is described mathematically. The piercing ability of a meteorite and crater shapes are discussed.

Chapter XXXI deals with the acoustics of colides and meteorites. A loudness scale is given. The reflection of sound waves in the stratosphere is discussed.

Chapter XXXII deals with meteoric seismic phenomena. Meteoric and meteoritic hyperseisms are discussed.

Chapter XXXIII deals with telescopic meteors, methods of observing them, their brightness, and their azimuths of distribution. Heights and radiants of telescopic meteors are discussed.

Chapter XXXIV deals with cosmic and meteoric dust in the terrestrial atmosphere.

Chapter XXXV describes meteoric matter on the earth's surface. Dust precipitation and its distribution on the globe is described. The work is based on 1,004 published Soviet and Western works.

30. Bronshten, V.A. Problem of Motion of Large Meteoric Bodies in the Atmosphere contains three chapters which deal with physical phenomena in the terrestrial atmosphere, which are associated with the motion of meteor bodies.

Chapter I contains five sections, which deal with the formation and shape of shock waves, the processes taking place at the front side of the shock wave, and the influence

of ionization on the structure of shock waves.

Chapter II contains five sections, which deal with the distribution of temperature and ionization in shock waves. Equations of ionization kinetics, ionization and recombination coefficients, and the time of ionization relaxation are given.

Chapter III deals with heat transfer to the meteor. Processes of heat conductivity and exchange are discussed mathematically.

The book is based on 124 published Soviet and Western works and presents a mathematical development of the problems discussed.

31. Simonenko, A. N. Treatment of Meteor Photographs is a small book in five parts, describing the approach to photographed meteors and photographic processing. The first part, entitled General Concepts, contains the general approach to the problem. The second part, Determination of the Coordinates of Meteor Positions from Photographs, deals with choice of basic stars, measurements of photographs, and the introduction of spherical coordinates with necessary corrections. The third part, Trajectories of Meteors in the Terrestrial Atmosphere, deals with the determinations of the pole of meteoric circle and the radiant, and the velocity of a meteor and its deceleration in the atmosphere. The fourth part, A Sample of Photograph Processing describes the operations which must be performed for determining the parameters of the basis, the coordinates of the meteor's position in the sky, the radiant, the height of the meteor at a given time, and its velocity and deceleration relative to the various positions in height. The fifth part, Checking of the Results by Graphs contains graphs of the magnitudes obtained. This small pamphlet may be considered as a practical application of the theoretical concepts expressed in the other books in this review.

WRITER'S COMMENTS: Meteoric phenomena have been widely investigated by Soviet scientists from the descriptive, theoretical, and chemical points of view. A special periodical, "Meteoritika," publishes papers dealing with the dynamic and physical properties and the chemical composition of meteors. Special attention has been given to the phenomena of meteor trails, the distribution of ionized gases, and telescopic meteors. With respect to the last topic, one group of investigators believes that telescopic meteors appear at the same heights as visible meteors. Astapovich and Terent'yeva arranged the heights of telescopic meteors in four groups ranging from 125 to 16 km. Lyubarskiy and Latyshev criticized this arrangement as being based on incorrect data and inappropriate processing methods. No final decision has yet

been reached as to th[illegible] meteors. The criticism of Lyubarskiy and Latyshev results from a subjective approach to the problem, as is evident in the article by these authors.

The distribution of ionized gas around the flying meteor is discussed in detail, and a model is given which delineates the gas zones in front of and behind the meteor. The layers of the trails are studied. The approach to the problem is sound, and results obtained elucidate both physical and chemical phenomena of meteors. In some cases, however, the authors permit personal preconceptions to influence their work.

A set of books published in the USSR represents a comprehensive study of the problem both from the theoretical and the experimental points of view. The books of Levin, Katasev, and Bronshten are of a theoretical nature in which the motion of meteors, the physical processes in the terrestrial atmosphere associated with moving meteors and the ionization of gases and the dissipation of meteor matter are studied in detail.

The [illegible] by Astapovich reviews the history of meteor observations and the development of meteor investigation from the theoretical approach. The text is mostly descriptive.

Fedynskiy's book is of a popular nature intended for a wide circle of readers. Simonenko's book is a short review of meteor observational data. It could serve as a guide for beginners of meteor investigations.

No comparable set of books exists in the West. This gap must be filled to further successful meteor investigations. Many interesting articles have been published in Western periodicals which could be used for compiling a good textbook on meteor studies.

Some comments on individual papers must be added. The paper by Alpert, Gurevich, and Pitayevskiy is a general review of investigations of a body's motion in plasma. Attempts are made to apply the theories discussed to special cases of practical importance, but are restricted by the authors' choice only to the simplest examples. The motion of artificial satellites and weather rockets in plasma was not taken into consideration. The study of the motion of these bodies is of special interest for astronavigation.

Lyubarskiy's and Latyshev's study of the distribution of meteors in space is important for investigation of interplanetary matter and astronautics. The author's approach

to this problem is rather subjective, and he indulges in some arbitrary preconceptions. The author's data on the meteor distribution in space, especially the telescopic meteors, is good, but the processing in some parts is based on preconceived methods like the projection of all radiants on the ecliptic plane and the use of the earth's apex as the fundamental direction of arrival. The earth's apex is a variable direction which can lead to misrepresentation of the true path of the meteor.

Fialko's conclusion as to the good agreement of his approximate coefficients (n) with theoretical results is open to question in view of his arbitrary assumption and his neglect of conditions which are characteristic of general cases.

Furman's study of the parameter changes is sound. The ionization process of a meteor train is unknown and impossible to investigate experimentally; it can only be assumed. This process in the upper atmospheric layers is very important for studying the interplanetary space. Furman's ionization parameters can elucidate, in some way, the series of processes occurring in the meteor path.

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